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Workshop on FireMod 1

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Lawrence
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Workshop on FireMod 1

An introduction to using a family of codes for simulation of integrated firing-system/initiation-trains*

Presented by

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December 4, 2000

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The FireMod family of codes

RingFit: Models RLC circuit parameters from a ring-down discharge current

ResFit: Fits the HFM resistivity model to current and voltage data from a bridge firing
Fits simulated power in bridge to current times voltage to adjust RLC circuit parameters for switch and inductance effects

FireWin: Simulates the bridge electrical discharge using HFM or Fireset models for bridge resistivity

KoFit: Fits parameters for bridge hydrodynamic equation of state to flyer velocity observations on test firings

KoCreate: Helps prepare input file for Kowin runs

Kowin: Performs combined electrical/hydrodynamic simulation of firing system

FireMod - a work in progress

- FireMod is under development – changes in member codes will be forthcoming
- RingFit, ResFit, and FireWin are at the "advanced beta test" level, and should see only minor changes
- KoFit is at the "beta test" stage, but may need changes to correspond to developments with Kowin
- Kowin is at an advanced stage in its present version, but a new version is planned to include a two-phase equation of state
- KoCreate is at an early, "pre-beta" stage, and has many improvements under development
- A new code is anticipated to be added to the FireMod family to provide scaling of bridge model parameters to situations not yet measured

Outline for the workshop

- First, examine common aspects of the codes
- Then, for each code in the FireMod family:
  1. Examine the theoretical basis
  2. Explain the required inputs to the code
  3. Display the "help" file for the code
  4. Install the code on the users' computers
  5. Run the example problem on the CD-ROM
- Give time for each participant to use the codes on example data or their own data – with assistance as needed

Codes' similarities

- All codes share the same format for input and output files, allowing output from one to be input for another.
- All codes that optimize use the same numerical technique.
- All codes have the same visual presentation (Kowin excepted)
- All codes have context sensitive help available (Kowin excepted) as well as detailed help files

Codes' differences

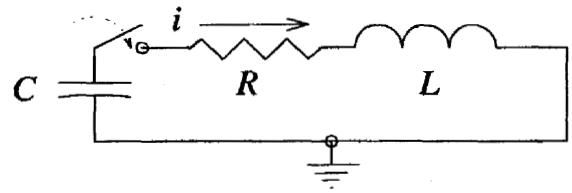
- RingFit is a simple code, has no extra screens.
- ResFit involves more complex optimizations, has two major presentation screens.
- KoFit is a controlling code for batch execution of Kowin, has long run times.
- FireWin duplicates and extends Fireset for a windowing GUI and has graphical and data file outputs.
- Input to Kowin is a text file – KoCreate is a GUI code to create Kowin input files.

Common features of all FireMod codes

- All codes have a top menu bar controlling the code.
- All codes (except Kowin) have context sensitive help (tooltips) which can be enabled from the "help" menu item.
- All codes have a help file which can be accessed from the "help" menu item.
- All codes read and/or write parameters to/from Kowin input format files (`.kow` files).
- All codes read and/or write data to/from standard text files having each line as a record of numbers separated by spaces.
- All codes expect auxiliary files (such as EoS libraries) to be in the same directory as the executable.

RingFit code theoretical basis

Simplified CDU slapper electrical circuit with bridge shorted:



Taking i as the current in the circuit, the circuit differential equation is

$$\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LC}i = 0. \qquad (1)$$

The solution of this equation is the damped sinusoid,

$$i(t) = I_m e^{-t/\tau}\cos[\omega(t - t_o)]. \qquad (2)$$

RingFit code optimization method

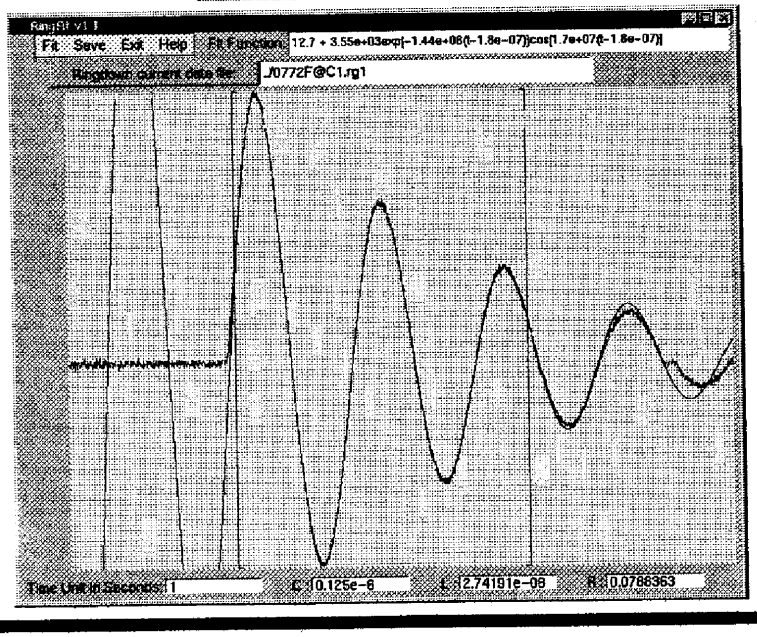
RingFit does a non-linear least squares fit of ringdown current data to the damped sinusoid: $i(t) = I_m e^{-t/\tau} \cos[\omega(t - t_o)]$.

R and L are calculated from τ and ω, given C.

$$\tau = \frac{2L}{R} \qquad \omega = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \tag{3}$$

$$L = \frac{1}{C[\omega^2 + (\frac{1}{\tau})^2]} \qquad R = \frac{2}{C\tau[\omega^2 + (\frac{1}{\tau})^2]} \tag{4}$$

Install and run RingFit



Sample output from RingFit

```
$-------------------------------------------------
$RingFit v1.2b Output:  Tue Nov 14 10:45:50 2000
$Data file: ../examples/0772F@C1.rg1
$Lower limit of time fit: 1.15422e-07,  Upper limit of time fit: 9.29094e-07
$Fit tol = 1.49012e-08,  Fit fnorm = 892.253,   Fit info = 1
$Fit function:
$     12.1095 + 3548.56exp[-1.43245e+06(t-1.8067e-07)]cos[1.70291e+07(t-1.8067e-07)]
$Time unit in seconds: 1
$RLC circuit values in SI units:
$          R = 0.0784796,  L = 2.73934e-08,  C = 1.25e-07
$Circuit values in ".kow" file format:
$ (replace "gamcu" by desired material name)
matinput gamcu eliginput
R 0.0784796 L 2.73934e-08 C 1.25e-07
```

#Help file for RingFit v1.2a - K.H.Carpenter - 19MAY00

"RingFit" fits data from the current in an underdamped RLC circuit to its theoretical damped sinusoid form, and calculates R, L, and C values, given one of them.

To use "RingFit":

1) Press the button labeled "Ringdown current data file:" This brings up the "file chooser" from which you may browse the file system and enter the file specification containing the data for the current in the RLC circuit which you wish to fit to find the RLC values.

   The browser is mainly self explanatory. However, to change to a different device under MSWindows, erase the entry box and place the letter, followed by a colon and a backslash, to get choices on the new device, e.g., "e:\"

2) If the file chosen in step one contains valid data, which must be two numbers per line, then the data will be autoscaled and plotted (in blue) with the first number on each line providing the horizontal value and the second number on each line in the input file providing the vertical value.

3) Click the left mouse button with the cursor on the plot at the horizontal left limit for curve fitting. Click the right mouse button with the cursor on the plot at the horizontal right limit for curve fitting.

4) Press "Fit" on the menu, and a least squares fit will be made of the theoretical RLC decaying sinusoid to the data between the red fit limit bars. The theoretical function will be plotted in magenta for all horizontal values. The data will be plotted in blue within the limits of the fit and green outside the limits. The theoretical function being plotted in magenta is given as a formula in the box labeled "Fit Function:"

5) Enter one of R, L, or C in the boxes at the bottom of the plot and the corresponding circuit values are calculated and shown in their boxes. When a new fit is made, the C value is retained.

6) If the time data in the input file used for the horizontal axis in the plot is not given in seconds, then enter the value of the time unit, in seconds, in the box labeled "Time Unit in Seconds" and the R,L,C values will adjust to correspond to it. When a new fit is made, the C value is retained.

7) Press "Save" on the menu to bring up the file chooser to select the name of an output file to which the fit data will be appended. (The default file is "ringfit.dat" in the current directory.)

8) Go back to step 3) to fit a different region of data, or go back to step 1) to fit data from a new file. Press "Exit" on the menu to quit.

Under the "HELP" pulldown menu, select "Tooltips" to have context sensitive help boxes displayed, corresponding to the location of the mouse cursor. Select "About RingFit" to have the window shown at start-up with information about the program and its copyright displayed.

ResFit code theoretical basis

ResFit ratios voltage to current data and fits it to the hybrid resistivity model:

$$\rho(g) = \begin{cases} \rho_i e^{g/g_i}, & 0 \le g \le g_1 \\ \rho_0 e^{-\left(\frac{(g-g_0)}{s_0}\right)^2}, & g_1 \le g \le g_2 \\ \rho_d e^{-g/g_f} + \rho_f, & g_2 \le g \end{cases} \tag{5}$$

ρ_0, g_0, and s_0 are the parameters of the Gaussian peak.
ρ_i is the parameter of the initial segment.
ρ_f and g_f are the parameters of the final segment.
g_1 and g_2 are the parameters separating the piecewise continuous segments.
g_i and ρ_d are not parameters but are set to values to make the function continuous.

ResFit code optimization method

Resistance fitting:

- ResFit estimates the parameters of the Gaussian peak from the location of the voltage maximum and the resistivity there.
- The Gaussian parameters are refined by doing a least squares fit to them over a region in specific action (g) set interactively.
- The values of the region separators g_1 and g_2 are set interactively.
- The initial estimate of ρ_f is set interactively.
- Least squares fitting may be done to refine any of these values.

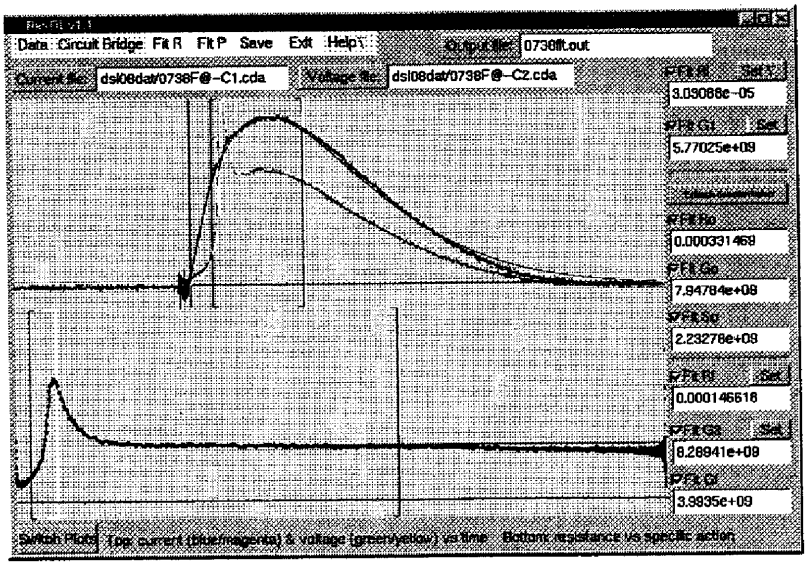
ResFit code optimization method

Power fitting:

After the resistivity function has been fit, circuit parameters may be optimized to give the best fit to power.

- Current data time zero must be properly chosen.
- Initial capacitor voltage may need to change for simulation from the recorded value to compensate for drop across the switch.
- The code does a non-linear least squares fit between power values from a simulation made by solving the circuit differential equations and the measured values of current times voltage (over the interactively selected region)

Install and run ResFit



Sample output from ResFit

```
$-----------------------------------------------
$#ResFit v1.2c Output:  Tue Nov 14 11:08:53 2000
$Current Data file: ../examples/0774cur.dat
$Voltage Data file: ../examples/0774volt.dat
$Time scale factor = 1, Current scale factor = 1, Voltage scale factor = 1
$Lower limit of time fit: 1.50499e-07,  Upper limit of time fit: 2.16998e-07
$Current zero level = 0, voltage zero level = 0
$Bridge dimensions (in mils):
$width = 10,   length = 10,  thickness = 0.175
$Fit tol = 1.49012e-08,  Fit fnorm = 413224,   Fit info = 2
$Last fit type: Power fit
$Parameters fitted: (0 for not fitted, 1 for fitted)
$   voltage data time delay, 0;   current time zero, 0;
$   Vo, 1;  R,  1;  L,  1;  C, 0;
$   Ro, 1;  Go, 1;  So, 1
$Parameter values:
$voltage time delay = 0 s,  current time zero = 1e-07 s
$RLC circuit values in SI units:
$          Vo = 2031.15,  R = 0.104639,  L = 3.61501e-08,  C = 1.25e-07
$Simple Gaussian model parameters:
$Ro = 0.000244928 (ohm-cm), Go = 2.38442e+09 ((A**2/cm**4)s), So = 1.06765e+09((A**2/cm**4)s)
$Initial exponential portion of Hybrid model parameters:
$Ri = 3.48606e-05 (ohm-cm), G1 = 1.375e+09 ((A**2/cm**4)s)
$Final exponential portion of Hybrid model parameters:
$Rf = -1.09535e-05 (ohm-cm), Gf = 4.4939e+09 ((A**2/cm**4)s),G2 = 2.51567e+09 ((A**2/cm**4)s)
$Model values in Kowin input format:
$ (replace "gamcu" by desired material name)
matinput gamcu eliginput bridgemodel 5
Ri 3.48606e-05 G1 1.375e+09
R0 0.000244928 G0 2.38442e+09 S0 1.06765e+09
Rf -1.09535e-05 G2 2.51567e+09 Gf 4.4939e+09
```

#Help file for ResFit v1.2b - K.H.Carpenter - 18MAY00

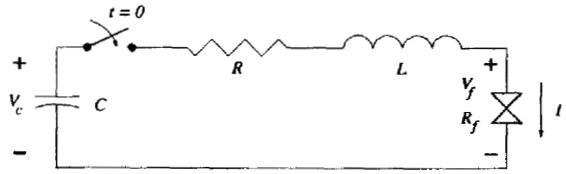
"ResFit" is a code to fit resistivity model parameters to experimental data from RLC firing systems.

To use "ResFit":

1) Enter input current and voltage data by clicking first on the "Current file" button and selecting the current data file to input; then click on the "Voltage file" button and choose the voltage data file to input.
2) If the files chosen in step one contain valid data, which must be two numbers per line, then the data will be auto-scaled and plotted (in blue for current and green for voltage) with the first number on each line providing time value (which must be the same for both files) and the second number on each line in the input file providing the vertical value. Current, voltage, and time scales may be adjusted if the files' units are not SI by clicking on the "Data" button. Black lines give the zero axes.
3) Click on the "Circuit" button and enter the data for the fireset obtained from "RingFit". Or click on the "LoadC" button and values will be read from the ".kow" format file chosen.
4) Click on the "Data" button and set the current time zero so that the vertical axis coincides with the place where a sinusoid fitting the initial rise of current would cross the zero axis. (When circuit parameters have been entered, clicking on "Push to estimate Current Time Zero" will enter an approximate value.) Then set the voltage time delay to make the current and voltage curves cross zero at the same time after the first maximum.
5) Click on the "Bridge" button and enter the dimensions of the bridge. The resistivity versus specific action plot will now appear in the lower half of the screen. Or click on the "LoadC" button and values will be read from the ".kow" format file chosen.
6) Click the left mouse button with the cursor on the plot at the horizontal left limit for curve fitting. Click the right mouse button with the cursor on the plot at the horizontal right limit for curve fitting.
7) Click on the "Fit R" button, and the Gaussian peak will be fit if the limits set in 6) are appropriate. If not, reset the initial "guess" by clicking on "Estimate model values".
8) Click on the "Set" button by "G1" on the right side of the screen, and then put the cursor on the resistivity plot where the connection between the initial exponential rise and the Gaussian peak should be placed.
9) Either select the physical value for "Ri" or check to fit "Ri".
10) Set the left fit limit to a location left of the yellow line that shows the location of "G1" and again click on "Fit R"
11) Click on the "Set" button by "G2" on the right side of the screen, and then put the cursor on the resistivity plot where the connection between the Gaussian peak and the final decaying exponential section should be placed.
12) Set the right fit limit some distance right of the yellow line showing the location of "G2" but left of the region where divergence of resistivity values occur due to the zero crossings of voltage and current.
13) Set to fit "Rf" and "Gf".
14) Click on "Fit R" There should now be a reasonable global fit to the resistivity curve, shown in magenta on the plot.
15) Click on "Switch Plots" to show the power versus time. Select fit limits (in red) appropriate to fitting power. If it is desired to vary fireset circuit parameters to match simulated power to experimental, then click on the "Circuit" button and check the parameters to vary.
16) Click on "Fit P" to display simulated power, voltage, and current, based on the resistivity fit. The circuit values will be optimized if checked for fitting.
17) Click on "Save" to write the results to the output file. If the left mouse button is used then the resistivity parameters are also saved in the ".kow" format. If the right mouse button is used then both the circuit parameters and the resistivity parameters are also saved in the ".kow" format.
18) Click on "LoadM" to read model parameters from the ".kow" formated file selected. (If you wish to try them as starting points for a fit or just to see how a fit to another file will do on this data.)
19) Vary parameters, enter a new file, or do whatever else is of interest.
20) Click on "Exit" to exit the program.

FireWin code theoretical basis

Simplified CDU slapper electrical circuit:



FireWin solves the circuit equation, for I as a function of t:,

$$L\frac{di}{dt} + (R + R_f)I + \frac{1}{C}\int I dt = 0. \tag{6}$$

The bridge resistance, R_f, is evaluated as a function of action, $G = \int I^2 dt$, from either the HFM model or the Fireset model equations. (HFM equations are above in "ResFit code theoretical basis," Fireset equations follow next.)

Fireset model resistivity equations

$$\rho = A\left[1 - \operatorname{sech}\left(\frac{g}{g_0}\right)\right] + B\exp\left[-\left(\frac{g - g_0}{s}\right)^2\right], \tag{7}$$

$$g_0 = G_0(V_0/KL)^P \qquad s = S_0(V_0/KL)^P. \tag{8}$$

Eq.(7) gives the resistivity of the bridge element in terms of four parameters:

A the resistivity after burst

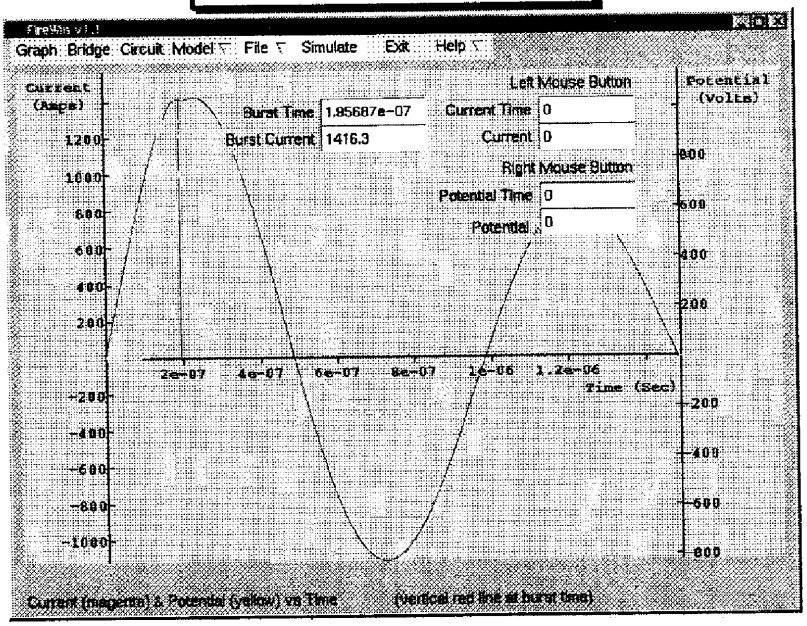
B the peak resistivity

g_0 the specific action to point of burst

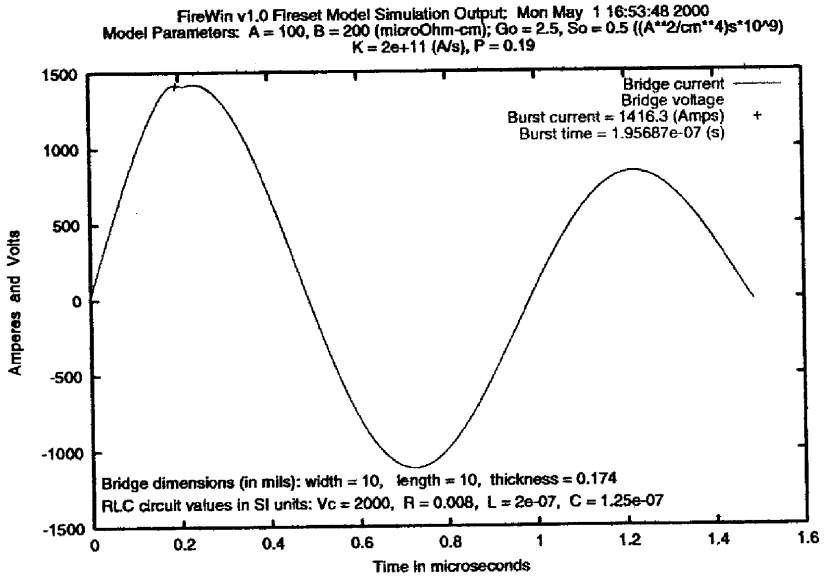
s the width of the resistivity peak.

The independent variable determining the resistivity ρ is the specific action g.

Demonstration of FireWin



Sample FireWin graphical output



Sample FireWin data output

```
#FireWin v1.0 Simulation Output:  Mon May  1 16:54:37 2000
#Bridge dimensions (in mils):
#width = 10,   length = 10,  thickness = 0.174
#RLC circuit values in SI units:
#Vc = 2000,  R = 0.008,  L = 2e-07,  C = 1.25e-07
#Fireset Model Parameters:
#A = 100 (microOhm-cm), B = 200 (microOhm-cm),
#Go = 2.5 ((A**2/cm**4)s*10^9), So = 0.5 ((A**2/cm**4)s*10^9),
#K = 2e+11 (A/s), P = 0.19

#Burst time = 1.95687e-07 (s), Burst current = 1416.3 (Amps)
#Time    I       IDot    SpecAction      V
0       0       1e+10   0       0
9.93333e-10     9.93307 9.99941e+09     259.247 6.24647e-11
1.98667e-09     19.8654 9.99842e+09     2073.87 1.29685e-10
2.98e-09        29.7965 9.99703e+09     6998.81 2.69781e-10
```

#Help file for FireWin v1.1a - K.H.Carpenter - 17MAY00

"FireWin" is a code to simulate RLC firing systems with two different bridge resistivity models: the Fireset model of Ron Lee (UICD-21322), and the hybrid model (HFM) using an exponential rise section followed by a Gaussian section to simulate burst resistivity, followed by an exponential decay section to final resistivity.

"FireWin" is intended to provide the functionality of the original FIRESET code, but with a graphical user interface compatible with contemporary windowing operating systems. In particular, "FireWin" will run under MS Windows: 95,98, and NT, and under X11R6 (with Linux or other Unix versions).

To use "FireWin":

0) If help is needed on using the program, click on the "Help" button and select one of the items.
    a) the "Help Screen" item will display this file.
    b) the "About FireWin" item display version and copyright information.
    c) the "Show tooltips" item will turn on the "tooltips" feature when selected (checked). This is recommended for new users. When checked, and the mouse cursor is held over a region having a "tooltip" associated with it, then a box opens on the screen with information about that feature of the code.

1) If parameters to be used for the simulation are available in a file following the input syntax for "Kowin", e.g., a ".kow" file, then they may be read into "FireWin" by selecting the "Load Parameters" item on the "File" menu which opens by clicking on the "File" button. These parameters may be modified, or entered originally via other menus described in the following.
2) Click on the "Circuit" button and enter the values for the RLC fireset (as would be obtained from "RingFit"). Also enter the initial capacitor voltage to be used for the simulation.
3) Click on the "Bridge" button and enter the dimensions of the bridge resistive element.
4) Click on the "Graph" button and enter the specifications for the time extent of the simulation and how it will be displayed.
    a) The end time for the simulation may be entered or may be estimated as 1.5 periods of the LC oscillation frequency by pressing the "Estimate.." button (provided L and C have already been entered for the circuit).

b) Either time between data points or total number of data points may be entered when the correct subwindow is selected by a checked box. The other will adjust automatically to correspond to the end time selected.

c) Check boxes may be marked to select grids for time, current, or potential across the bridge.

5) Click on the "Model" button to bring up the model menu and select the model to use and open a window in which to set the model parameters.

a) If the Fireset model is selected, the default parameters shown, if no "Load Parameters" action has been taken previously, will be those for copper as given in the original Fireset code by Ron Lee. Note that the action parameters will scale in the Fireset model depending on the voltage and capacitance value. The units for entering these parameters in this window are the same as used with the original Fireset code interactive input.

b) If the Hybrid model is selected, the defaults are all zero, and all values must be entered here or via "Load Parameters". The units used in this window are the same as the units used in the .kow file, and are not the same as the units for the similarly named parameters in the window for the Fireset model. The best way to get entries for this window is by a run of "ResFit". And "ResFit" can output a .kow file to input with "Load Parameters".

6) Click the "Simulate" button to cause a simulation using the most recent set of parameters. The simulation may fail if some of the parameters are inconsistent. In this case an error message will pop up. The simulation results will be plotted in the graph area of the main window. If specific action reached the action-to-burst value during the simulation then the burst current and burst time values will be displayed in output boxes so labeled, and a red vertical line will be drawn at the burst time on the plot.

7) The values of current or potential corresponding to a given location on the plot may be displayed in the boxes so labeled by pressing the left mouse button at the point on the plot where the time and current values are desired, and by pressing the right mouse button at the point on the plot where the time and potential values are desired.

8) Click on the "File" button to bring up the menu to load, save, or print parameters and data.

a) the "Load Parameters" item opens a file chooser window in which to specify the .kow syntax file to read to find simulation parameters.

b) the "Save Parameters" item opens a file chooser window in which to specify the file name to be used to write the most recently entered set of simulation parameters to a .kow syntax file for future use by "Load Parameters". Note that this appends the parameters to the file, leaving the previous contents of the file in place. When "Load Parameters" encounters two instances for the same parameter, the last one will be the one used.

c) the "Save Simulation" item opens a file chooser window in which to specify the file name to be used to save the current, current time derivate, specific action, and potential across the bridge in a format which can be input for "gnuplot" or other external data analysis programs.
Note that this save will overwrite a file of the same name already present rather than append to it.

d) the "Print Simulation" item causes a printed version of the information to be produced. Under MS Windows the printer dialog box will open to allow choosing which printer to use. Under Linux or Unix a temporary file containing Postscript code will be produced. It must be sent to a printer by a separate user command. The single page of output produced will have a plot of current and voltage labeled with the parameters of the simulation.
(These labeled plots are produced by a special version of the "gnuplot" program, which must be installed and in the current path.)

9) To capture a screen image of the current window, under Microsoft Windows (NT or 98), hold down the "Alt" key and press the "Print Scrn" key.] This copies the image of the active window to the "clipboard." You can then "paste" the clipboard image into MSPaint or MSWord or a similar program.
Under Linux or Unix to capture a screen image from an XWindows screen use the "xwd" program (part of X11) or the "import" program (part of the ImageMagick package).

10) Click on the "Exit" button to close all windows and leave the program.

KoFit, KoCreate, and Kowin codes

KoFit determines parameters associated with the bridge region equation of state.

KoCreate provides a menu driven, graphical user interface for producing a Kowin input file.

Kowin is a one-dimensional hydrodynamics code containing the circuit simulation needed for electrical ignition of bridge elements.

- One must understand the Kowin code to successfully use either KoFit or KoCreate.
  (See: Steinberg, "Equation of State and Strength Properties of Selected Materials," UCRL-MA-106439)
  (See also the demo Kowin input below)
- KoCreate is in an early stage of development and not ready for "production" use.

The Kowin user interface

- Input is through a text file using keywords followed by their values
  - Keywords are grouped by function
  - Many keywords have synonyms
- Input files may be edited with any text editor or with "Koed"
  - Koed is a typical MS Windows editor, similar to "Notepad," but is coupled through its menu bar to Kowin.
- Output is through plots versus space or time of state variables
  - Any output plot may have its data saved to a file for use with external plotting or calculation programs.
  - Saved file names are based on the input file name and have a number appended which is incremented for each save.
  - Different runs on the same input file will cause output files to be overwritten as the names will be the same.

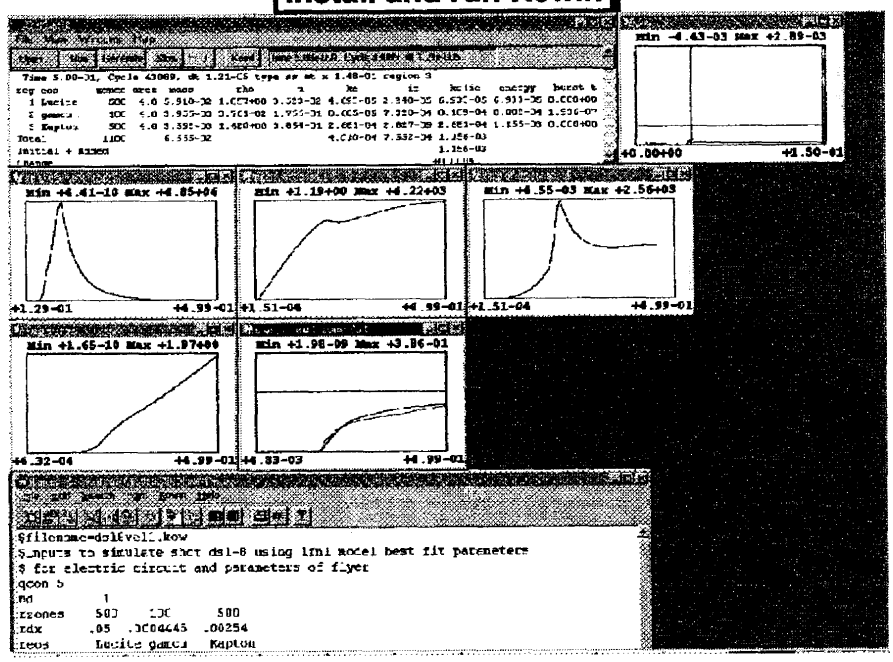
A simple demonstration Kowin input file with comments

```
id 20 mm he .5 mm cu flat plate
                                    $ id is used for descriptive purposes only
nd 1                                $ geometry for problem, 1 is planar
rzones    8       0   200        50  $ no of zones in each region
rx0  0.                             $ this is default
rupper   .0254   .1    *          *   $ upper boundary of each region, * is null
rdx       *      *    1.995     .0526 $ width of each region
reos   micarta  void LX-14-0  cop  $ material for each region
ru        .43                       $ initial velocity of each region

graphback 1 ask 1                   $ black frame for graphics, ask before quiting
endtime = 5.  dtmore .5             $ time to run to, will run further in increments of dtmore

Matinput micarta GrunToPoly         $ gruniesen is unstable at high pressure so switch to polynomial
Matinput Cop kowineos Cu
  pmin -.006 pmspall                $ use copper eos with new name and modifications

SNAPSHOT p+q   ymin 0. ymax .50     $ plot p+q vs. x, with y maximum of .5
     ymark .380 xmin 0. xmax 3.     $ put y reference line at .38, limit x range

Snapshot eta  reg 3                 $ plot eta vs. x, for region 3 only, x and y auto scaled
 time 2.0 dt .2 endtime 5.          $   begin at 2, replot every .2 until 5

AddFile plotu.txt                   $ add this file to input, gives u vs. t with data plot

Versus P eta reg 2 zone 100         $ plots P vs. eta for zone 100 of HE region

                                    $ many more options available, see help package
```

Part of a Kowin input file showing circuit parameters

```
$filename=flyer03-2b.kow
$Inputs to simulate shot flyer 03 774 using lfm1 model best fit parameters
[lines omitted here]
nd          1
rzones     500     44       254        500           5
rdx       .05   .0004445   .00254     .254         .05
reos       Lucite gamcu    Kapton          air    PBX9404
re0          *     .00000001         *           *         *
[lines omitted here]
matinput gamcu rho 8.9 iform 5 coef 1.15 ihe 0
   eliginput bridgemodel 3 vc 1900 c 0.125e-6 1 3.2e-8 r 0.0808
   ecoh 5.32e6 evpo 1.409e6 sp 4. abd 1
   length 0.0254 width 0.0254 thickness .0004445
   A 7.14e-14 B 315e-3 G0 2.499e9 S0 49.910e9 P 0.0001 K 5.9375e10
   R0 1.7e-6 D 1.53e-3 G1 1.4798e9 G2 2.928e9 G3 865e6

SNAPSHOT p cycle 0       ymin 0. ymax .05   ymark .01 xmin 0. xmax .15
addfile vel3.dat
versus reg-ep time 0 dc 100 reg 2
versus reg-I time 0 dc 100 reg 2
[lines omitted here]
```

Install and run Kowin



KoFit code for optimization of Kowin parameters

- KoFit uses the same non-linear least squares method as RingFit and ResFit
- KoFit runs a batch version of enhanced Kowin (Kobat) as a background process
- Simulated flyer velocities are compared to measured ones to do the fit
- Kowin parameters that can be fit are
  - "gamma" for the gamma law equation of state
  - "ecoh" the energy required to convert the bridge to the gaseous state
  - "evpo" the energy limit where electrical circuit energy begins to smoothly couple to the bridge region in the hydro-code
  - "sp" the energy coupling transition shape factor

Sample KoFit input file

```
$filename=hfmkof.kow
$example form for use with kofit - khc - 02jun00
$Inputs to simulate shot flyer 03 774 using hfm model parameters
$Velcity data is in file vel3s.dat -- initial portion with different
$ time sample rate has been edited out from data file for shot 0774
$Velocity data used with kofit must have uniform time samples
$
$"matinput gamcu" below gives initial values for copper foil
$used with this shot.  Values may be modified by file "kofitpa.in"
$to generate best fit
$
qcon 5
nd          1
rzones     500     44       254
rdx       .05   .0004445   .00254
reos       Lucite gamcu    Kapton
re0          *     .001         *
ru           0.      0.       0.
rx0         0.
lb 2  rb 2
ucut 1e-12
dtmin = 1e-10
endtime = .3  dt 5e-5
ecut 1e-11 $-1
pcut 1e-8
cyclemod 100
plotdc 0
plotvdc 0
ecmax 1e5
matinput gamcu rho 8.9 iform 5 coef 1.15 ihe 0
   eliginput bridgemodel 5 vc 1900 c 0.125e-6 l 3.2e-8 r 0.0808
   ecoh 5.32e6 evpo 1.409e6 sp 4. abd 1
   length 0.0254 width 0.0254 thickness .0004445
   Ri 1.7e-6 G0 1.27729e9 S0 2.7991e8
   R0 3.354e-4 Rf 1.478e-4 G1 7.50e8 G2 1.3217e9 Gf 6.2796e8

$SNAPSHOT p cycle 0       ymin 0. ymax .05   ymark .01 xmin 0. xmax .15
$versus reg-ep time 0 dc 100 reg 2 $win 300 200 150 125 dc 20
$versus reg-I time 0 dc 100 reg 2  $win 450 200 150 125 dc 20
$versus reg-vf time 0 dc 100 reg 2 $win   0 325 150 125 dc 20
$versus reg-ee time 0 dc 100 reg 2
$versus reg-g time 0 dc 100 reg 2
$versus reg-u time 0 dc 100 reg 3
addfile kofitpa.in
```

Sample KoFit-written "kofitpa.in" file

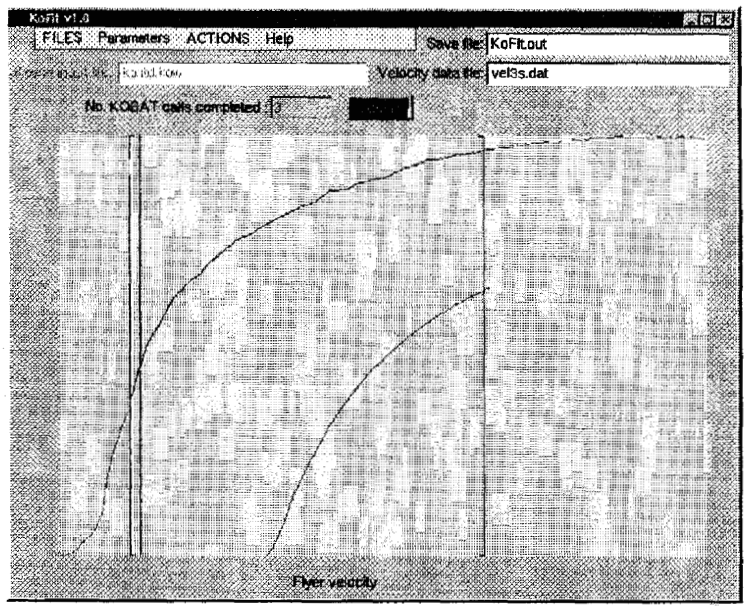
```
endtime 0.1365510322580645
matinput gamcu rho 8.9 iform 5 coef 1.289282566518277
eliginput ecoh 5320000 evpo 4161890 sp 3.87516
VERSUS reg-u time 0 vdt 0.0009753645161290321 dt 0.0009753645161290321
endtime 0.1365510322580645 yreg 3
```

Sample velocity data file to use wit KoFit

(First three lines in this file allow it to also be input to Kowin. They are ignored by KoFit.)

```
VERSUS u time 0 vdc 10 dc 50 ymin 0. ymax .8   ymark .5  yreg 3 yzone 254
datadx 0.1 $ 0.47e-1
data
-0.036953 0.0627565e-1
-0.0359777 0.0686839e-1
-0.0350023 0.0687423e-1
[... 305 lines of data omitted ...]
0.263459 5.09779e-1
0.264435 5.0936e-1
0.26541 5.09097e-1
```

Install and run KoFit



Sample KoFit output file

```
$-------------------------------------------------
$#KoFit Output:  Tue Nov 14 10:48:44 2000
$Velocity Data file: vel3s.dat
$Time scale factor = 1, Velocity scale factor = 1
$Lower limit of time fit: -0.00933604,  Upper limit of time fit: 0.116977
$Velocity zero level = 0,  velocity time zero = -0.09
$Fit tol = 1.49012e-08,  Fit fnorm = 0.106861,   Fit info = 2
$Parameters fitted: (0 for not fitted, 1 for fitted)
$   velocity time delay, 0;   gamma, 1024;
$   rho, 0; ecoh, 0;  evpo,  0;  sp,  0;
$Parameter values:
$velocity time delay = 0 us,  gamma = 1.15979
$  rho = 8.9, ecoh = 5.32e+06,  evpo = 4.3e+06,  sp = 4
$Model values in Kowin input format:
$ (replace "gamcu" by desired material name)
matinput gamcu rho 8.9 iform 5 coef 1.15979
eliginput ecoh 5.32e+06 evpo 4.3e+06 sp 4
```

#Help file for KoFit, v1.1 - K.H.Carpenter - 02JUN2000

"KoFit" is a code to fit ideal gas model parameters in Kowin to experimental velocity data from RLC firing systems.

The user interface for KoFit is similar to that for ResFit. See the ResFit "help" for instructions on how to select menu items, etc.

To use KoFit, first a Kowin input file must be produced (using Koed or some other text editor) which specifies the situation to be simulated. Note that for flyer velocity measurements only three regions are required: backing, foil, flyer. Adding others only slows computation time.

The Kowin input file must give the electrical circuit parameters (as obtained, e.g., from RingFit and ResFit) and the complete specifications for simulation. The material for the bridge must be named "gamcu" for KoFit to input changes properly. This Kowin input file must not contain any "snapshot" or "versus" graphics requests. The last line in the file must be "addfile kofitpa.in". Kofit will write the file "kofitpa.in" to communicate values of parameters being fitted to "kobat".

This Kowin input file will be run in a batch version called "kobat" under control of KoFit. The "kobat.exe" executable must be in the same directory as the "kofit.exe" executable. The EOS files used by "kobat" must be in the same directory as the executables. The file USER.EOS may be optionally located in the current working directory. (But if KoFit is started from a MSWindows "shortcut" the the current working directory will be the one in which the executable is located.)

One should test this Kowin input file by running it in Kowin once directly (or in "kobat" directly). Watch for "negative density" errors in the foil region. These can be removed by changing the (fictitious) initial internal energy parameter re0 to a greater value.

When running under control of KoFit, "kobat" may encounter a "negative density" error or some numerical problem that will cause it to stop before reaching the desired end time. (If so, KoFit will report the failure to reach the end time and abort the fit.) This may be due to fit parameters being set to non-physical values by the search routine. To eliminate this, restart the fit with initial parameters nearer to final ones and/or change the region of the fit and/or the time delay between the measured and simulated velocity. (If gamma ¡= 1, KoFit will signal an error and require manual restarting of the fit.) (One may see the parameters that were most recently sent to "kobat" by "kofit" by examining the file "kofitpa.in" in the same directory with the Kowin input file being used. Look especially for negative values, which in most cases are non-physical.)

Steps for use of KoFit:

1) Choose Kowin input file to be used by clicking on "Kowin input file:" button and using the file browser window that is opened.

2) Choose input velocity data file by clicking on "Velocity data file:" button and using the file browser window that is opened.

3) If the file chosen in step two contains valid data, which must be two numbers per line, then the data will be autoscaled and plotted (in blue) with the first number on each line providing the horizontal value and the second number on each line in the input file providing the vertical value. Black lines give the zero axes.

4) Click the left mouse button with the cursor on the plot at the horizontal left limit for curve fitting. Click the right mouse button with the cursor on the plot at the horizontal right limit for curve fitting.

5) Click on the "LoadP" button to open a file browser from which to choose a ".kow" file from which the parameters described in steps six, seven, and eight may be read. The values read will replace any values that have already been entered.

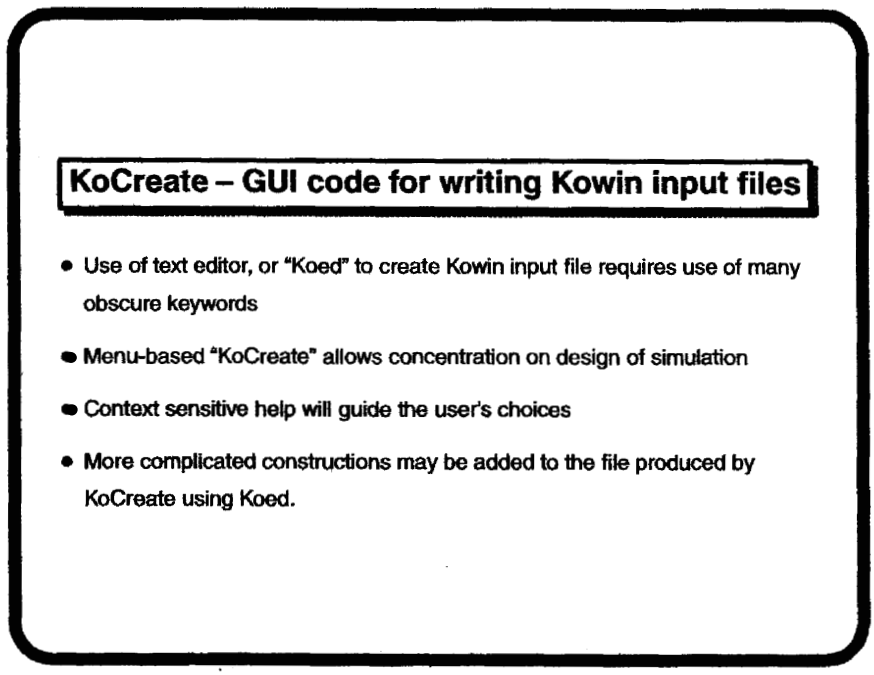
6) Click on the "EoS" item on the menu and then enter initial values for the equation of state parameters for the fit. (Default value present on start-up are appropriate initial values for copper bridges.) Also click the box for each parameter to be fitted. (Try to keep the number of values fitted small until near the optimum.)

7) Click on the "Kowin" item on the menu and then enter the region number for the flyer velocity being simulated. (The default is 3.)

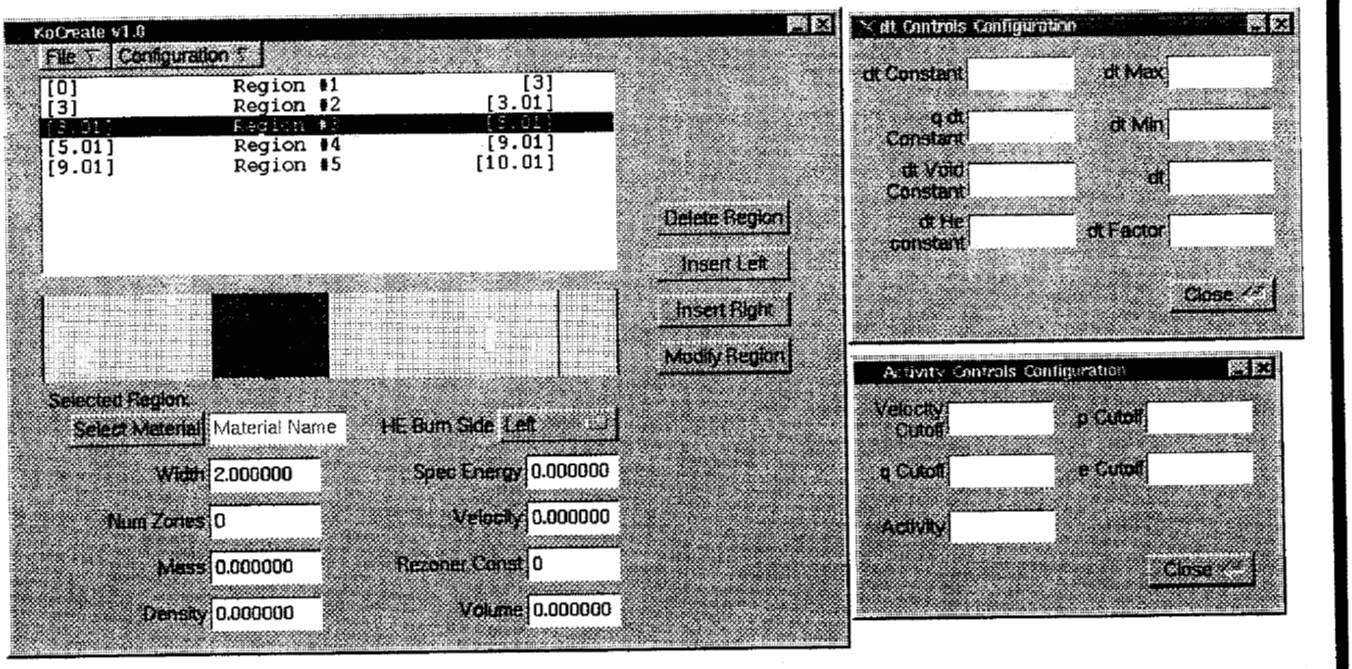
8) Click on the "Data" button and enter the "Velocity time zero" value needed to relate the simulated and measured velocities. The value must be that of the time in the measured data file that corresponds to current start in the fireset. (Note that the "Velocity time delay" and "Velocity time zero" parameters are not independent. The "Velocity time zero" value should be set from

data provided from the experiment. The "Velocity time delay" is then the change needed to provide the best simulation. Note that automatic fitting of this value is not implemented in the current version of KoFit.) (If the number of initial values to average for zero level is set to zero then no voltage zero offset is done.)

9) Click "Fit" on the menu to do the fit. It may take some time, depending on how many values are being fitted and how close the initial parameters are. The best fit velocity curve will now be displayed in the region of the fit. To interrupt the fit click on the "Stop fit" button. The fit may be restarted from the same point by clicking on "Fit" again. The parameters at this degree of fit may be saved by clicking on "Save". (Note that there may be time delays between clicking on "Stop fit" and the actual stopping of the "kobat" process, depending on the speed of the computer.)
10) You may change parameters or choices for parameters to be fitted and fit again. (Press "Stop fit" button first if fit still running.)
11) To save the information from the fit to a file, click "Save" on the menu.
12) Click on "Exit" on the menu to quit the program.



Demonstration of KoCreate



KO for Windows Help

Contents

KO for Windows (KOWIN)

Introduction/Abstract

KOWIN is an implementation of the basics of the KO one dimensional hydro code for the PC. It is designed to run in an interactive environment and does not use any of the original KO code. It is written in C++ and is intended to be a simple basic hydro code that can easily accept new models. The code is faithful to the KO differencing equations in almost all respects. Minor changes have been made in some cases for ease of implementation and enhanced stability. The major differences include the void closure which is done over a number of cycles, rather than in one cycle. The cold and melt curves for the Steinberg-Guinan model are implemented as a table lookup rather than a polynomial and are calculated automatically at the time of generation. The time step controls implementation is different and uses different constants. Depending upon the form of an equation of state and the users input, the sound speed for a material can be calculated from the derivatives of the equation of state, from a constant gamma, or numerically.

An EOS data base is included in the file KOWINEOS.TXT. EOS's are named rather then numbered, although numbers are permitted and the familiar KO numbers are available as synonyms.

Several of the more exotic models present in the KO code are not implemented at this time, nor are they planned to be included in future versions. These include reactive flow, the Bauschinger effect, and equation of state multipliers. Rate dependence for the material strength, is not implemented at this time but will be in the future.

The code is in the C++ language. The code is designed to be easily modified. Most data storage is dynamically allocated so there are no limits on the number of zones, equations of states , etc. New variables may be easily added and automatically included in the IO structure. The code can run problems of modest size on a 486-DX2 or better processor in a few minutes and IO is available interactively. Memory requirements are modest, even for the largest problems.

Problem Setup

General

KOWIN has a wide variety of input variables and options. Most are defaulted to "reasonable" values, so that a typical input file is small and compact. The input is case insensitive and space delimited. For the purpose of clarity all KOWIN input words are capitalized in this section. Numbers are format insensitive and all the usual formats are supported. The input is context sensitive, so the same word may be used in different contexts. The main context is GLOBAL which contains variables which apply to the entire problem. This is the default context and usually does not need to be stated. Other variables which define their own contexts are MATINPUT, VERSUS, SNAPSHOT, and TABLEINPUT. ELIGINPUT defines a subcontext within MATINPUT. Contexts can be nested. Words are read until the parser finds a word it doesn't understand, and then the parser returns to the previous context, continuing until the word makes sense. If a word is not found generation is terminated and a text editor is activated for the file. Since most words in KOWIN are unique, input for a particular context does not need to be terminated, however, should confusion arise DONE will terminate a particular context.

The order of input is arbitrary and, with the exception of string input and comments, is not line oriented. For string input a string is read to the end of a line unless it is quoted (in which case other keywords may follow on the same line). Note that strings can contain KOWIN input words which will be considered part of the string. Input which requires a single word as input is not considered a string, but may be quoted if desired. Comments are begun with a $ and extend to the end of the line. ON and OFF are synonyms for 1 and 0 respectively. * is used in region definition to indicate no value.

The units used in KOWIN are cm, gm, and μsec. These units are not hardwired and can be changed by writing over default constants and control numbers. The major determinant of the units is the EOS database and the gasR variable. The EOS database is contained in the ASCII file KOWIN.EOS and can be replaced with an alternate. Also a user EOS database (user.eos) can be used. Similarly EOS's may be overwritten by MATINPUT.

Operations

KOWIN requires a number of files for the code to function properly. Included in these files are the EOS data base KOWIN.EOS, the editor KOED.EXE, the help file for the editor, and the KOWIN help file. All of these files should be in the same directory as where the KOWIN executable was installed . When KOWIN runs it checks to see if it has been registered, if it has not it asks if you want to register it. When it is registered the directory from which it was run becomes its default directory. Should you wish to change directories use the windows utility regedit to delete the KOWIN entry and run the code from the new directory or simply reinstall to a new directory. When KOWIN runs it looks for files (except .eos files) first in the directory containing the input(.KOW) file and then in the default directory. Input files should have the extension .KOW. Double clicking a .KOW file will start KOWIN, read the file and generate. It will also run the problem, if RUNIT is set to ON in the input file. Input files may also be opened using to Open button or file menu when KOWIN is running. The generate button will regenerate a problem using the current input file, unless you are using the editor, in which case it uses the editor contents.

Program execution is stopped by either using the run/stop button or by the ENDTIME or ENDCYCLE global variables. When one of these variables stops execution using the run button will cause the program to continue running. The number of cycles or time to run beyond the end is controlled by global input variables DCMORE and DTMORE. The slow and fast button control the speed at which the calculation proceeds. When the fast button is disabled the calculation

proceeds as fast as possible. When the slow button is disabled the calculation proceeds at one cycle per second. This allows the viewing of events that may otherwise pass by too rapidly.

KOWIN uses a number of different EOS databases. The primary database is KOWIN.EOS which contains metals and other materials. Another database is HE.EOS which contains HE data. If the code is linked to CHEETAH there will also be a database for it. There is also a provision for a user database, USER.EOS. If the user wishes to develop their own EOS library this file should be used. It will not be written over by reinstalling and will not be deleted by the uninstall procedure

KOED, the KOWIN editor, is a separate program which will communicate with KOWIN if it is invoked from KOWIN. This is accomplished by double clicking the edit window. If there is an error in the input, KOED will be run automatically if it is not already running and will select the first occurrence of the word which gave it trouble. Selecting the green Generate button on the tool bar will cause the problem to regenerate from the KOED data and not the file itself, i.e. you need not save the data to disk to make changes. If the editor is not present KOWIN will use the current input file to regenerate.

Region and Grid Definition

The geometry of the grid is determined by the ND variable, where 1 is Cartesian, 2 is cylindrical, and 3 is spherical. LB and RB define the left and right boundaries respectively. 1 is rigid and 2 is free. The default is 2 except for the left boundary which is 1 when ND is 2 or 3 and rx0 is 0.

As with KO a grid is divided into regions. Regions are numbered from left to right starting at 1. Voids are not counted, although they must be included in the input which is used to generate regions. The equations of state for the regions are specified by the REOS variable, which is a string of EOS names. Each region must have an EOS assigned to it. The same EOS can be used for different regions. Voids are designated by VOID or 0. RZONES give the number of zones in each region, The number of zones in a void is ignored, but it must be an input. Both REOS and NZONES are required input. Note that unlike KO there is no central void input for spherical and cylindrical geometry's. To input a central void set RX0 to the coordinate of the inside of the first region, the central void is then taken care of automatically.

The grid is defined by the variables RX0 or X0, RUPPER or RX, RDX, RMASS, RV0, RRHO. RX0 is the position of the left side of the grid, it is defaulted to 0. RUPPER is the coordinate of the right side of a region. RDX is the thickness of a region, RMASS its mass, RV0 its initial volume, and RRHO is its actual density(not rho0). The V0 of the EOS will be used if RV0 is not input. Any combination of these variables can be used to specify the grid. If a particular region is over specified then, if possible, the V0 for the region is changed to resolve the over specification. If this is not possible the over specification is ignored. The grid is built from the left to the right. For RDX and RMASS input the grid will be built from right to left starting from the next defined value of RUPPER. If RX0 is -1 and RMASS for region 1 is specified then RX0 will be calculated from the mass. If RMASS is negative this region will be used to resolve any over specified region. For example

```
RX      5  *   10
RMASS   * -200  300
```

will result in region 2's density being reset to resolve the over specification, otherwise region 3's density would be used.

The final variables controlling the initial grid definition are RE0, RAREZ, RU, and RIGN. RE0 is the initial energy in the zone. If it is not input then the E0 of the EOS is used. RAREZ is the rezoner constant for a region, if it is not input the automatic rezoner will not operate in this region. RU is an initial velocity for a region, and RIGN is used to ignite HE.

Graphics and main window display

The main window is used to display various quantities. The class of variables displayed can be selected from the view menu. When starting to run the region variables are automatically selected. The list of variables for the grid display may be changed in the input file by using the edit command. The font size may be selected from the view menu.

To graphically display various variables during a run use the SNAPSHOT and VERSUS keywords in the input file. SNAPSHOT plots a variable vs. x at the current cycle. VERSUS plots any variable in the grid vs. any other variable in the grid over the entire run of the problem. If only one variable is specified for VERSUS the other variable is defaulted to time. The location of a variable in the grid is specified by the XREG, YREG or REG, XZONE, and YZONE or ZONE variables. If the zone input is negative the reference is from the right of a region otherwise it is from the left. For SNAPSHOT input REG limits the plot to the input region and in combination with REGMAX it will plot from REG to REGMAX regions. Zone input is ignored in SNAPSHOT input.

Each SNAPSHOT or VERSUS creates a new window with the default characteristics. An unlimited number of plots may be displayed subject to the limits of the computer. A wide variety of controls are available for SNAPSHOT and VERSUS plots. Default is to automatically scale the plots to the maximum and minimum values of x and y. All of these defaults may be overridden in the input file. Unless otherwise specified the size and position of the plot windows are determined by the size of the display and the available room. The plots are refreshed automatically at a rate of ~ 20 frames per second (simulated time – not real time). The overall refresh rate is controlled by the global variable DISPLAYDT and default window size by WINX and WINY. With the exception of DISPLAYDT most values can be overridden for individual plots. With a large number of plots a significant amount of the run time can be spent refreshing the display and so calculation time can be saved by altering the refresh rate.

Double clicking with the left mouse button or clicking the right mouse button over a plot window brings up a menu which allows the data to be saved or viewed. The copy option copies data to the clipboard in a tab delimited format which can be pasted into most spreadsheet and ploting programs. The save data option allows further specification of how the data is saved and also will save the data to disk. The copy bitmap option copies the image to the clipboard. The view option allows viewing of the data in the main window.

Electric Ignition

Incorporating electric ignition into Kowin

Electric ignition, using a capacitive discharge circuit connected to an exploding bridge, has been integrated into the Kowin program by solving the RLC circuit and adding the energy deposited in the bridge to the region which constitutes the bridge material. For Cartesian symmetry a bridge foil is used along with an adjacent region representing the "slapper." (For cylindrical symmetry a round bridge wire is used for which the cross sectional area must be the same as the product of length and width entered to the code. The bridge model is not appropriate for use with spherical symmetry.)

The capacitive discharge is initiated at time zero. The time steps used by Kowin are dictated by the hydrodynamics calculations – the electric circuit solver uses its own internal time steps. The progress of energy transfer to the bridge region and the resistance change of the region may be monitored by plotting **versus** curves of variables related to the discharge calculation such as **reg-ep, reg-ee, reg-I,** and **reg-vf**. The time of burst may be seen on the main window when the region variables are displayed there.

Four models are available for the bridge material electrical resistance in the circuit simulation. When **bridgemodel** = 1, the Fireset model of Ron Lee is used. (Firset is based on specific action.) When **bridgemodel** = 2, the resistance model of Carlton Furnberg is used. (This model is based on constant current data.) When **bridgemodel** = 3 an enhanced hybrid model also based on action but having some of the functional form of the Furnberg model is used. When **bridgemodel** = 5 the simplified hybrid model that is fitted to data with the **ResFit** code is used. (A fifth choice of **bridgemodel** = 4 activates use of directly specified energy pulses without circuit simulation.)

Coupling electrical energy to the hydrodynamics code

The circuit simulation calculates the electrical energy dissipated in the resistance model representing the bridge. This energy cannot be entirely transferred to the hydrodynamics code. Allowance must be made for the way the bridge material is represented in the hydrodynamics calculations, and compensation must be made for the fact that not all the bridge material is in position to transfer its energy to subsequent portions of the 1-dimensional hydrodynamics system.

Compensation for bridge material cohesive energy

In order to allow a simple gamma law equation of state to be used for the bridge material, the material's cohesive energy must be removed from the electrical energy deposited into the bridge before calculating the pressure from the equation of state. This is accomplished in the following manner.

The Eliginput variable **ECOH** is given a non-zero value near the per unit mass cohesive energy. The value of **ECOH**, which is specific energy in Joules/kg, is multiplied by the mass of the bridge to obtain a threshold value for electrical energy. (The simplest compensation would be to wait until the electrical energy deposited in the bridge resistance exceeds this threshold before adding the subsequently generated electrical energy to the region corresponding to the bridge in the hydrodynamics part of the code. Unfortunately, an abrupt start of energy transfer causes a shock in the hydrodynamics code which may not be realistic.) Since the bridge material does not go instantaneously from a solid to a vapor (which may be represented by a gamma law equation of state) a gradual increase of the coupling of electrical power to the hydrodynamics code is needed. The material first must liquefy and then vaporize. Little expansion will occur until the vaporization begins. Thus from the standpoint of simulation of the effect of the bridge on the

adjacent material, some energy should begin to be added at the onset of vaporization and the full amount coupled after vaporization is complete. An additional input value is needed to represent this onset.

The Eliginput variable **EVPO** is given a value corresponding to the internal energy of the bridge material at the onset of vaporization. **EVPO** is a specific energy in Joules/kg. **EVPO** is used with **ECOH** to calculate the fraction of electrical power to transfer to the hydrodynamics calculation when the electrically obtained energy is between these values. The coupling of power begins at zero when the electrical energy to the bridge resistance reaches **EVPO** times bridge mass. The coupling of power increases to 100% when the electrical energy to the bridge resistance reaches **ECOH** times bridge mass.

The function that varies the coupling of the energy from the electrical simulation to the hydrodynamics code has a form that can be varied by means of the Eliginput variable **SP**. For larger values of **SP** energy transfer begins slowly and increases rapidly as ECOH is approached. For small values of **SP** (less than one) the rate of energy transfer increases rapidly from zero and is close to 100% for most of the range between **EVPO** and **ECOH**. For **SP** = 1 the coupling increases in a symmetrical manner, not linearly, but based on a sinusoid.

Compensation for bridge material in the electrical circuit not adjacent to the other material of the hydrodynamic system

Electric current continues to flow in the bridge circuit after burst time (when complete vaporization occurs in the portion adjacent to the other material to which it couples in the hydrodynamic code and an electrical arc is initiated in the vapor). The bridge total resistance does not drop to the low value which would be consistent with the arcing through the vapor. This is due to continued vaporization of portions of the bridge material that is outside the region which couples hydrodynamically to other materials. To represent this phenomenon Eliginput variable **ABD** is given a non-zero value. The power coupled into the hydodynamics code after burst time is multiplied by an attenuation coefficient. This coefficient is a negative exponential function of specific action minus specific action at burst. The value of **ABD** scales the exponential argument, with larger values giving a faster attenuation of coupling. (Values of **ABD** near one are likely to be appropriate.)

An amount equal to the energy coupled to the hydrodynamics code from the electric circuit is added to the "initial energy" value in the code. This is necessary to prevent a failure of the "energy check" test.

Magnetic force effect in bridge material

When the parameter **TWIDTH** is positive it is used to calculate a magnetic force term. The external magnetic field in the bridge is estimated as the field due to a uniform current in a strip line having width **TWIDTH** at a location close to the surface compared to the width. The force per unit volume is calculated as this external field times the current density in the bridge. The force per unit volume is multiplied by the thickness of a zone to obtain the magnetic force acting on the zone. This force then adds to the hydrodynamic forces from other causes when calculating the acceleration of the zone.

The magnetic force model is restricted to cases which have planar geometry. If used when the geometry is set to cylindrical or spherical the results will be meaningless. The magnetic force model also neglects the pinch effect of the field generated by the current in the bridge zones themselves on the bridge zones. The magnetic force model uses too high a value for the external field when the bridge material is moved from its original position by an amount significant compared to **TWIDTH**. Compensation to the "initial energy" value is made for the energy added to the hydrodynamics code by the work done by the magnetic force. The reason for this compensation is to prevent a failure of the "energy check" if the amount of work were to become

significant. (The actual energy supplied by the magnetic force comes from the change in self inductance of the electrical circuit -- this change in self inductance is not modeled in the code but should be insignificant.)

Alternate energy models

In addition to the three circuit simulator generations of energy to couple to the bridge material in the hydrodynamics code, provision for direct specification of an energy pulse has been provided for **bridgemodel** = 4. In this case, Eliginput variable **K** has value 1 for a rectangular pulse and value 2 for a triangular pulse. **ECOH** give the total specific energy to be coupled (in Joules/kg) by the pulse while **A** is the initial time (in microseconds) of the pulse and **B** is the final time of the pulse.

Global Input

Geometry

- **nd** - number of dimensions 1 Cartesian, 2 cylindrical, 3 spherical
- **lb** - left boundary, 1 is rigid, 2 is free,
  default 2 for Cart., 1 for others with rx0 = 0
- **rb** - right boundary,1 is rigid, 2 is free, default is 2
- **rx0** or **x0** - origin of grid, defaults to 0, cannot be < 0 for nd = 2,3

Region definition

- **rzones** - no of zones in each region **required**
- **rz** - synonym for **rzones**
- **reos** - eos name for each region,
  list of names extends to end of line if not quoted **required**
- **rupper** - upper boundary of a region
- **rx** - synonym for **rupper**
- **rdx** - width of a region
- **rmass** - mass of a region, if negative indicates over determined region
- **rrho** - actual density of region
- **rv0** - actual relative volume of region
- **re0** - specific energy of region
- **ru** - velocity of region, includes both boundaries
- **rign** - HE burn ignition for region: 1 is left side, -1 right side, >1 all.
- **rarez** - automatic rezoner constant, default 4

Voids

- **closedc** - number of cycles for void closure, default 9
- **closef** - factor for momentum transferred in one void closure cycle, default .5

dt controls

- **dtcon** - sound speed dt constant default .7
- **dtqcon** - q dt constant default .1
- **dtvoidcon** - dt constant for void closure .2
- **dthecon** - maximum HE burn fraction in one cycle, default .2
- **dtmax** - dt maximum for problem default 10,000.
- **dtmin** - dt minimum default 1e-6
- **dt** - dt at start of problem default 1e-6
- **dtfac** - factor by which dt is allowed to rise in one cycle default 2

activity controls

- **ucut** - velocity cutoff to prevent noise default 1e-9
- **qcut** - q cut off default 1e-9
- **pcut** - p cut off ,can also be input with an eos, default 1e-9
- **ecut** - e cut off, default 1.e-10
- **activity** - activity test flag, default is 1 - on

stop run conditions

- **endtime** - time to run to default a large number
- **endcycle** - number of cycle to run default 10,000
- **ecmax** - maximum energy check allowed, default .05
- **dtmore** - delta time to run on restart after reaching endtime, default 1
- **dcmore** - delta cycles to run on restart after reaching endcycle, default 100

edit controls

- **edit** - list of variable names to edit, maximum is 8, no minimum.
- **regdt** - time interval for region summary edits default 0 i.e. null
- **regdc** - cycle interval for region summary edits default 50
- **regtime** - time at which to start region edits

regcycle - cycle at which to start region edits

miscellaneous

nogruneisan - converts all gruneisan EOS's (iform 4) to polynomials (iform 52)
qcon - default q constant for the problem, default value 2.
qfb - default linear q constant, default value 0.
qlim - monotonic q constant, turns off von Neuman q, default .8
qlimb - linear monotonic q constant, default .5
addfile - name of file to add to input
id - string to identify problem, extends to end of line if not quoted
arezmem - factor for memory for rezoner, default 1.4
cyclemod - cycle interval to display time, dt, default 10
nolt - large number for lighting time in dynamic lighting, default 1.e10
graphback - background color for graphs, 0 is white, 1 black.
plotdc - default cycle increment for plots, default is 20.
plotdt - default time increment for plots, default is 0.
plotvdc - default cycle increment for versus data, default is 1.
plotvdt - default time increment for versus data, default is 0.
displaydt - real time dt (ms) to update graphics, plotdc and plotdt must be 0
winx - graph window x dimension, default depends on screen resolution
winy - graph window y dimension, default depends on screen resolution
ask - ask before closing window or quitting, default is 1 - on
global - sets input to global parameters, usually not needed
runit - if ON run problem if it generates, default OFF
mx0 - horizontal position of main window on the screen
my0 - vertical position of main window on the screen

Graphic Input

Snapshot (keyword) indicates a snapshot graph, must be followed by 1 or 2 variable names.
Versus (keyword) indicates a versus graph, must be followed by one or two variable names

data - data to plot, format is x,y .....
datadx - offset to add to data x value
regon - flag to plot region boundaries, default on.
xmin - minimum x for plotting, if not input will be autoscaled
xmax - maximum x for plotting, if not input will be autoscaled
ymin - minimum y for plotting, if not input will be autoscaled
ymax - maximum y for plotting, if not input will be autoscaled
labelsoff - turns off labels on graph
time - time to start display of plot
vtime - time to start collecting versus data, default is time
endtime - time to end display of plot
vendtime - time to end collecting versus data, default is endtime
dt - delta time for plot
cycle - cycle to start display plot
vcycle - cycle to start collecting data, default is cycle
endcycle - cycle to end display of plot
vendcycle - cycle to end collecting data, default is endcycle
dc - delta cycle for plots, default is PLOTDC
win - x y dx dy of window on screen, default none, none, 300,200
ymark - y position of a horizontal reference line on plot
lt - line thickness, integer 0 and 1 are the same
ltd - line thickness for data plot
pts - plots points instead of line, point size set by lt
ptsd - plots data points instead of line, point size set by ltd
ltype - line type f 0 solid 1 2 3 4 give options, works only with lt of 0 or 1
ltyped - data line type f 0 solid 1 2 3 4 other options, works with ltd of 0 or 1
xlim - calculate max and min only with in x limits of graph
vdt - for versus delta time to collect points
vdc - for versus delta cycle to collect points, default is PLOTDC
vmaxn - for versus the number of points to reserve memory for, default 2000
reg - name or no of region, for snapshots limits plotting to this region
regmax - for snapshots if input plotting range is from reg to regmax
yreg - for versus the region for the y variable, **reg** will substitute for this.
xreg - for versus the region for the x variable
xzone - for versus the zone number for the x variable, negative counts from top
yzone - for versus the zone number for the y variable, negative counts from top
zone - same as **yzone**
xstart - for versus data collection won't start until x variable is >xstart
ystart - for versus data collection won't start until y variable is >ystart
max - for versus specifies maximum of variable, reg variables control region access. If and x variable is specified it will be at same zone as y variable.
min - for versus, same as max except minimum value

EOS Input

EOS-matinput, is followed by EOS name

kowinEOS - name of EOS to use from kowineos library, must follow EOS name

iform - form number for the EOS, types supported:

- 1 - JWL
- 2 - 7 term polynomial
- 22 - 7 term polynomial, B1 = B0 in expansion
- 52 - 5 term polynomial, B1 = B0 in expansion
- 3 - 28 term polynomial
- 4 - Gruneisan
- 45 - linear Us-Up expanded to 5 term polynomial
- 5 - gamma law, input is gamma, not gamma-1
- 110 - 1D table look up for HE
- 130 - 2D table look up

jwl - use JWL EOS form, no value

poly7 - use 7 term polynomial (22) EOS form, no value

poly5 - use 5 term polynomial EOS form, no value

poly28 - use 28 term polynomial EOS form, no value

gruneisan - use gruneisan EOS form, no value

gammalaw - use gamma law EOS form, no value

1dtable - use 1D table lookup EOS form, no value

gruntopoly - convert from gruneisan input to 5 term polynomial EOS form, no value

table - table name for table lookup EOS's

rho - rho0 for the EOS (gm/cm^3)

v0 - initial specific volume, can be over written by region input

e0 - initial energy, can be over written by region input

coef - coefficients for the EOS as many as need by the form

qcon - quadratic q constant for the EOS, over writes global qcon

qfb - linear q constant, overwrites global qfb

qlim - monotonic q constant, defaults to global value, if >0 = 0

qlimb - linear monotonic q constant, defaults to global value.

ssgm1 - if non zero used for fast sound speed calculation, max gamma -1

beta - gamma + 1 for HE detonation

betaburn - turns beta burn on and off, default is on

ltprog - turns program burn on and off - default is off

ltdynam - turns dynamic lighting times on and off, default is off

fign - ignition burn fraction for dynamic lighting times, default is .4

detvel - detonation velocity for program burn. non zero turns program burn on

dettime - time to add to all program burn times.

ltfac - factor to multiply the calculated burn time across a zone

ffail - burn fraction in beta burn for det failure, if fraction < this HE det will fail

fmin - minimum for burn fraction, used to suppress noise

fmax - burn fraction above which fraction is set to 1. default .95

pcut - noise cutoff for pressure, over rides global input

pmin - minimum pressure for this EOS

sstype - sound speed calculation, 0 use default, 1 use ssgm1, 2 numerical derivative

isol - yield model, 0 none, -1 constant yield, 1 Steinberg Guinan

cmu - modulus of elasticity, Steinberg Guinan Go

y - yield strength, Yo

au - Steinberg Guinan- pressure and temperature dependence, A

bu - Steinberg Guinan- pressure and temperature dependence, B

yb - Steinberg Guinan- work hardening, β

yc - Steinberg Guinan- work hardening, n
gam0 - Steinberg Guinan- work hardening, εi
ywhmax - Steinberg Guinan- work hardening, Ymax
ycp - Steinberg Guinan ,specific heat for cold curve, Cp
gzyz - Steinberg Guinan - cold curve constant, γ0
wyz - Steinberg Guinan - cold curve constant, a
tmyz - Steinberg Guinan - cold curve constant , Tmo
ayz - Steinberg Guinan atomic weight- used as alternative to ycp
ye - Steinberg Guinan - exponential melt term - not supported
yp - Steinberg Guinan - exponential melt term - not supported
ratedep - Steinberg Guinan - rate dependence flag - default is off
slc1 - Steinberg Guinan- rate dependence, C1, if 0 no rate dependence
slc2 - Steinberg Guinan- rate dependence, UK
slc3 - Steinberg Guinan- rate dependence, Yp
slc4 - Steinberg Guinan- rate dependence, C2
ystrmx - Steinberg Guinan- rate dependence, maximum yield strength, Y*max
ecetamin - Steinberg Guinan , minimum eta for cold curve
ecetamax - Steinberg Guinan , maximum eta for cold curve
iecpts - Steinberg Guinan , no of points in cold curve table
CBspall - Turns on Cochran Banner spall model, default is OFF
spall - spall yield strength in Cbspall, Σ
dam0 - damage constant in Cbspall, D0
pcrush - pressure at which spall is healed, ie dam -> 0.
pmspall - uses pmin for pressure if p is < pmin.
cheetah - turns on cheetah input if cheetah is present

TableInput, is followed by the name of this set of table data
iform - type of table, may also be set in MATINPUT
110 for 1D, 130 for 2D, 135 for 2D LLNL-EOS
For 1D and 2D:
eta - compression scale (low to high) (ratio of specific volume to initial value)
For 1D:
p - pressure data (synonym for Xep below) (corresponding to eta entries)
Xep - (synonym for p)
For 2D:
e - energy scale (low to high) (Mbars) (energy divided by initial volume)
(can't use **e** if it follows a number for a previous table entry or it will be read by Kowin as 0.e0. Use **Ep** instead.)
p - pressure data (synonym for Xep below)
Pa - reference pressures (Mbars – corresponding to eta entries)
Ea - reference energies (Mbars – corresponding to eta entries)
Ep - Energy primes (synonym for e above)
Xep - Multiplier table entries (ordered by Ep then eta)
Te - temperature entries
ss - sound speed entries
For 2D-LLNL-EOS:
eta - density (gm/cc)
Ep - specific energy (erg/gm)
ss - sound speed (cm/sec)

EligInput
bridgemodel - 1 for Fireset model of Ron Lee (default),
2 for resistance model of Carl Fumberg
3 for enhanced hybrid model
4 for direct energy pulse synthesis
5 for ResFit hybrid model (HFM)

(if bridgemodel is 1, 2, 3, or 5 the following are used:)
VC - initial charge on capacitor in volts (default is zero)
C - capacitance in Farads (default 5e-7)
L - inductance in Henries (default 9e-8)
R - resistance (not included in bridge) in Ohms (default 0.075)
Length - length of bridge (in direction of current flow) in cm (default 0.0508)
Width - width of bridge in cm (default 0.0508 = 20mils)
Thickness - thickness of bridge in cm (default 0.000508)
(same as **rx** for region -- but must be entered separately)
EVPO - vaporization onset energy of the bridge material in Joules/kg (default -1)
SP - transition function parameter (default 1)
ABD - after burst energy coupling decay coefficient (default 0)
TWIDTH - width of strip transmission line from which bridge formed in cm (default 0)
If positive, magnetic force is calculated,
otherwise magnetic force ignored
(if bridgemodel is 1, 2, 3, 4, or 5, the following is used:)
ECOH - for bridgemodel 1, 2, 3, or 5:
cohesive energy of the bridge material in Joules/kg (default 0)
- for bridgemodel 4: total specific energy to be coupled in Joules/kg
(if bridgemodel is 1, 3, or 4, the following are used:)
A - for bridgemodel 1:
after-burst resistivity parameter in Ohm-cm (default 1e-4)
- for bridgemodel 3:
slope parameter in first region in Ohm-cm^5/amp^2-sec
- for bridgemodel 4: start time in microseconds for pulse
K - for bridgemodel 1 or 3:
inductance multiplier for g0 and s0 scaling in amp/sec (default 2e11)
- for bridgemodel 4: pulse shape value (1 for rectangular, 2 for triangular)
(if bridgemodel is 1, 3, 4, or 5, the following are used:)
B - for bridgemodel 1 or 3:
peak resistivity parameter in Ohm-cm (default 2e-4)
- for bridgemodel 4: stop time in microseconds for pulse
- for bridgemodel 5: initial resistivity in Ohm-cm
RI - synonym for **B**
(if bridgemodel is 1, 3 or 5, the following are used:)
G0 - base specific action at burst in amp^2-sec/cm^4 (default 2.5e9)
S0 - base peak width in amp^2-sec/cm^4 (default 0.5e9)
(for bridgemodel = 5 no scaling is done, the values of **K** and **P** are ignored, and **G0**, **S0** are used for g0, s0)
K -
P - power for g0 and s0 scaling (default 0.19)
(if bridgemodel is 2, the following are used:)
EB - energy at burst in joules (default 0.242)
AB - peak resistance coefficient in Ohms (default 5.704)
AS - peak width in joules (default 0.75)
NF - exponential decay coefficient (default 1.3)
KF - after burst resistance in Ohms (default 0.19)
SWPT - coefficient for switch from Gaussian to exponential decay (default 1.09)
(if bridgemodel is 2, 3 or 5, the following is used:)
R0 - for bridgemodel 2:
initial resistance in Ohms (default 0.005)
- for bridgemodel 3:
initial resistivity in Ohm-cm
- for bridgemodel 5:
peak resistivity of Gaussian region in Ohm-cm
(if bridgemodel is 3 or 5, the following are used, and have zero for default values)

D - for bridgemodel 3:
exponential after burst resistivity amplitude in Ohm-cm
- for bridgemodel 5:
asymptotic final resistivity of third region in Ohm-cm

RF - synonym for **D**

G1 - base specific action where initial linear section meets Gaussian in amp^2-sec/cm^4

G2 - base specific action where Gaussian section joins exponential decay in amp^2-sec/cm^4

G3 - base specific action divisor for exponential decay argument in amp^2-sec/cm^4

GF - synonym for **G3**

(note that for bridgemodel 5 none of the specific action parameters are scaled and the base values are the ones used)

Variable Names

Grid Variable Names

x	- grid position right(top) of zone
u	- velocity right(top) of zone
p	- pressure for zone
e	- energy for zone
v	- relative volume of zone
q	- "q" for the zone
V0	- initial volume of the zone
density	- actual density of the zone
vdv	- dv divided by v
dv	- volume change
t1	- temporary variable
t2	- temporary variable
t3	- temporary variable
t4	- temporary variable
burnfrac	- HE burn fraction
burntime	- time at which an HE zone burned
burnx	- x coordinate at burn time
str	- radial stress
stt	- tangential stress
epsr	- radial strain
epst	- tangential strain
ssum	- sum of stresses
eps	- equivalent plastic strain
edst	- energy source term
dr	- initial zone width (can be modified by rezoning)
melt	- melt factor for zone, 1 is melted
eta	- compression
p+q	- pressure + q
detvel	- actual detonation velocity after HE has detonated
ss	- sound speed
te	- temperature
yield	- yield strength
ywh	- work hardening yield strength
accel	- acceleration
ltime	- HE lighting time
ldt	- HE burn time across a zone
dam	- CB spall model accumulated damage
fdam	- CB spall model factor to multiply strength
x0HE	- det point x, dynamic lighting times
t0HE	- det time, dynamic lighting times
fmag	- magnetic force per unit area

Region Variable Names

reg-u	- average velocity for region, momentum/mass
reg-ke	- kinetic energy of a region
reg-ie	- internal energy for a region
reg-te	- total energy of a region (reg-ie + reg+ke)
reg-v	- specific volume for a region
reg-eta	- compression for a region
reg-rho	- density of a region

reg-vc - voltage on capacitor connected to region (with electric ignition on)
reg-I - current through bridge
reg-vf - voltage across bridge
reg-g - specific action of bridge
reg-ee - total energy deposited in bridge by electric current
reg-ep - power coupled to bridge material from electric circuit
reg-bt - burst time for bridge (0 before burst)
reg-bc - burst current for bridge (0 before burst)

Global Variable Names

dt - dt for problem
time - problem time
TECheck - Energy Check for problem

EOS's in alphabetical order

KOWIN EOS Data base (KOWIN.EOS)

Note - Any gruneisan form 4 equation can be turned into a more stable polynomial by setting iform to 45 or using GrunToPoly keyword

Description	Name	Form
Aluminum (Al 1100-0)	**AL1100-0**	Gruneisan
Aluminum (Al 2024-T4)	**Al2024-T4**	Gruneisan
Aluminum (Al 6061-T6)	**Al6061-T6**	Gruneisan
Aluminum (Al 7075-T6)	**AL7075-T6**	Gruneisan
Beryllium (Be)	**Be**	Gruneisan
Copper (Cu OFHC 1/2 Hard)	**Cu**	Gruneisan
Fansteel 85 - 61%Nb-28%Ta-10%W-1%Zr	**Fansteel**	Gruneisan
Gold (Au),	**Au**	Gruneisan
Graphite	**Graphite**	Gruneisan
Kel-F (C2F3Cl)	**Kel-F**	Gruneisan
Lead (Pb)	**Pb**	Gruneisan
Lexan (Polycarbonate)	**Lexan**	Gruneisan
Lithium (Li)	**Li**	Gruneisan
Lithium Fluoride (LiF)	**LiF**	Gruneisan
Lucite (PMMA)	**PMMA**	Gruneisan
Magnesium (Mg AZ31B)	**Mg**	Gruneisan
Mercury (Hg)	**Hg**	Gruneisan
Micarta	**Micarta**	Gruneisan
Molybdenum (Mo)	**Mo**	Gruneisan
Monel (66%Ni-29%Cu-3%Al-1/2%Ti)	**Monel**	Gruneisan
Nickel (Ni)	**Ni**	Gruneisan
Niobium (Nb)	**Nb**	Gruneisan
Platinum (Pt)	**Pt**	Gruneisan
Polypentene (CH2)	**CH2**	Gruneisan
Silastic (APC 2.5)	**Silastic**	Gruneisan
Silver (Ag)	**Ag**	Gruneisan
Stainless Steel (21-6-9)	**SS21-6-9**	Gruneisan
Stainless Steel (304)	**SS304**	Gruneisan
Stainless Steel (4340 RC38)	**SS430**	Gruneisan
Steel (Vascomax 250)	**SSVa250**	Gruneisan
Tantalum - 10% Tungsten (Ta - 10% W)	**Ta10%W**	Gruneisan
Tantalum (Ta)	**Ta**	Gruneisan
Teflon	**Teflon**	Gruneisan
Thorium (Th)	**Th**	Gruneisan
Thulium (Tm)	**Tm**	Gruneisan
Tin (Sn)	**Sn**	Gruneisan
Titanium - 6% Aluminum - 4% Vanadium	**TiAlV**	Gruneisan
Titanium (Ti)	**Ti**	Gruneisan
Tungsten - 3.5% Nickel - 1.5% Iron	**WNiFe**	Gruneisan
Tungsten (W)	**W**	Gruneisan
Tungsten Carbide (WC)	**WC**	Gruneisan
Uranium - .75% Titanium (U - .75% Ti)	**U.75%Ti**	Gruneisan
Uranium - 5% Molybdenum (U - 5% Mo)	**U5%Mo**	Gruneisan
Uranium (U)	**U**	Gruneisan
Vanadium (V)	**V**	Gruneisan

KOWIN	SYNONYMS

Ag	Silver
Al1100-O	Al Al1100
Al2024-t4	Aluminum2024-T4
Al6061-T6	
Al7075-T6	
Au	Gold
AuCu	GoldCopper
Be	Beryllium
C	Graphite
Cd	Cadmium
Cu	Copper Cu-OFHC
Fansteel	Fansteel85
Hf	Hafnium
Hg	Mercury
Kel-F	C2F3Cl
Lexan	
Li	Lithium
LiFl	LithiumFlouride
Lucite	PMMA
Mg	Magnesium AZ31B-H24
Micarta	
Mo	Molybdenum Moly
Monel	
Mulberry	UNbZr
Nb	Niobium
Ni	nickel
Nylon	
Pb	Lead
Polyethylene	
Polypentene	
Polystyrene	Foam
Pt	Platinum
Ptlr	PlatinumIridium
Silastic	APC2.5
Sn	Tin
SS-21-6-9	SS21-6-9 Stainsless21-6-9 Steel-21-6-9

SS-304	StainlessSteel304 Steel304 SS304
Steel-250	S250 Vascomax250 Vascomax Steel250 SteelVascomax250
Steel4340	S4340RC38 S4340 Steel-4340
Ta	Tantulum
TaW	TantalumTungsten Ta10W
Teflon	
Th	Thorium
Ti	Titanium
TiAlV	TitaniumAlV
Tm	Thulium
TungstenCarbide	Wcarbide
TungstenPlastic	Wplastic rattan
U	Uranium
Umo	uraniumMoly
UTi	UraniumTi
V	Vanadium
W	Tugnsten Wolfram
WNiFe	TungstenNiFe TungstenNickelIron
Zn	Zinc
Zr	Zirconium Zirc

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